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VISUAL TELEPHOTOMETRY

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Telephotometry, in its broadest sense, implies the measurement of the candle-power or brightness of light-sources which are situated a long way from the observer. The subject was originally of interest mainly to astronomers who, in connection with the determination of stellar magnitudes, developed various methods for comparing the intensities of stars.

At first the comparison of stars was made by the unaided eye; later it was made by bringing telescopic images of the two stars to be compared into juxtaposition by means of inclined prisms or mirrors, as in the case of Pickering's Meridian Photometer([1]). Sometimes an artificial star was used and the real stars were compared with this in turn; a typical example was Zöllner's photometer([2]), in which polarizing prisms were used to vary the apparent intensity of the artificial star.

In more recent times photographic and photoelectric methods have been developed, each having its own technique and its own problems. An adequate discussion of the whole field would be beyond the limits of a single paper. If, however, the subject-matter of the paper is restricted to the measurement of the candle-power or brightness of distant sources with special instruments called telephotometers, the ground to be covered becomes more manageable. The scope of this paper has therefore been confined to a discussion of the principles, advantages and methods of use of three main types of visual telephotometers. As these telephotometers were devised principally for the measurement of atmospheric transmission it will not be inappropriate to approach the subject from this standpoint. The problem of measuring atmospheric transmission involves in any case the measurement of candle-power or brightness. Most telephotometers, of course, are not restricted to this application.

Visual telephotometers can be classified into three main groups:

(a) Those used for the direct comparison of point sources (often referred to as stellar photometers);
(b) Those with which an external diffusing surface is compared with a diffusing screen incorporated in the instrument; and
(c) Those depending on the Maxwellian View principle.

I. Point-source Telephotometers.

If a light-source subtends a sufficiently small angle at the eye, its visibility (apparent intensity) is independent of its brightness or size and depends only on its total candle-power, its distance from the observer's eye, and its spectral composition. The visibility is in fact proportional to the illumination reaching the observer's eye from the source. The limiting angular size of such a source, which is termed a "point source" by photometricians, has been variously stated by different investigators and is largely dependent on the conditions of experiment. The retinal image of a true point source is actually a diffraction pattern consisting of a relatively bright circular disc surrounded by alternate dark and bright diffraction rings. The radius of the first diffraction minimum subtends at the nodal point of the eye an angle equal to $1.22\frac{\lambda}{d}$, where d is the effective diameter of the eye-pupil and λ the wavelength of the light from the source; the value of this angle is thus dependent on the wavelength of the light and on the diameter of the eye-pupil, which in turn will be affected by experimental conditions. With a pupil diameter of 4.5 mm. and a wavelength of 0.56μ, the angular diameter of the first dark ring is very nearly one minute of arc, and it is probably safe to say that a source which subtends at the eye an angle not exceeding this value behaves photometrically as a point source.

Telephotometers used for measuring or comparing the intensities of point sources may be of two types. In one type the distant source is compared with an artificial star incorporated in the instrument: in the other type there is no comparison source; provision is made for dimming the distant source until it is just invisible. Telephotometers equipped with an artificial star must be provided with some means of varying the intensity of this source or that of the source under observation. In earlier instruments the comparison source was usually adjusted; it is, however, better to adopt the alternative method, which permits all observations to be made at a constant value of eye-illumination determined by the comparison source. In practice an eye-illumination of 10^{-7} to 10^{-8} foot-candles has been found satisfactory for making measurements. By keeping the intensity of the comparison source low, accuracy of measurement is improved, owing to the reduction of irradiation effects. A modern example of the artificial star type is described by Middleton ([3]), and is shown in Fig. 1. In this in-

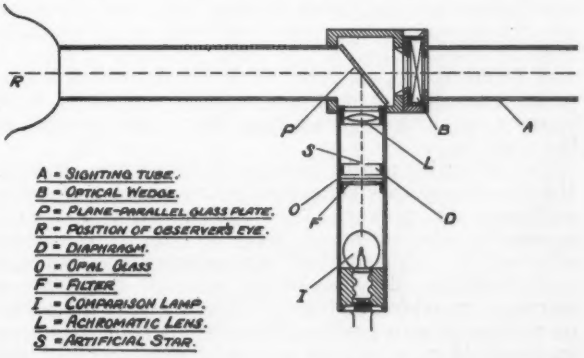

Fig. 1

strument light from a distant lamp passes along the axis of the tube A, through the variable density wedge B and the inclined plane-parallel glass plate P into the observer's eye placed at R. The plate P, set at 45 degrees to the axis of the observing tube, reflects light from an artificial star S consisting of a minute hole in a metal diaphragm D. Immediately below this small hole are fitted a piece of opal glass O and a blue "daylight" filter F, the latter being interposed in order that the small lamp I illuminating the opal glass may be run at a low efficiency. An achromatic lens L, adjustable vertically, forms a virtual image of the hole S at infinity. With the eye accommodated for infinity, the observer sees two point sources sharply focused in the field of view. The wedge, which controls the illumination reaching the eye from the distant lamp, is adjusted until the two point sources appear of equal intensity.

It may be appropriate at this point to consider some of the difficulties which are encountered when two point sources are viewed simultaneously. The sensitivity of the retina is by no means uniform. The visual acuity is highest in the fovea, and the Purkinje effect appears to be absent in this region. On the other hand, at low field-brightnesses the contrast sensitivity is lower at the fovea than in the surrounding region. Except when the light is red in colour the effect of changing from foveal to parafoveal vision under these conditions is easily demonstrated, for, if a point source is first regarded directly and then obliquely considerable brightening will be noticed when the image falls on the parafoveal region. (For red sources there appears to be very little difference between the foveal and parafoveal contrast sensitivities.) Generally, to ensure that two point sources are being compared under the same conditions, foveal vision only can safely be used in the comparison.

If the image of an object at which an observer is looking is to fall completely within the fovea, the object cannot with safety subtend at the eye an angle greater than one degree. In the comparison of two point sources the observer would probably fixate on one; in this case, for the image of the other to fall on the fovea, the angle of separation between the two sources could not safely exceed half a degree. Comparisons under such conditions are not easy, for even when an observer is certain that both sources are focused on the fovea he may still find comparison troublesome on account of their relative closeness to one another in the field of view. Paterson and Dudding (4), in their work on the visibility of point sources, found it impossible to work with sources so close together that they were viewed at the same time.

The difficulty can be avoided in two ways. In one, the two images are separated by an angular distance sufficient to prevent their being viewed simultaneously; the observer looks at the two sources alternately. This method was adopted by Paterson and Dudding. In the other method, a prism or mirror is provided in the instrument; with the prism or mirror in one position the distant source is seen in the field of view; by a lateral movement of the prism or mirror the distant source is obscured and the comparison source appears by reflection in approximately the same position in the field. In both cases the observer sees the two sources alternately, and adjusts one of them until their apparent intensities are the same; while looking at one source he has to carry in his mind an impression of the intensity of the other. In calibrating an instrument of this type, the prism or mirror is tested with the comparison source as a unit.

The construction and calibration of the comparison source are details on which the whole performance of the instrument depends. The construction is a matter of some difficulty; the problem is to make a round hole of the order of one-hundredth of a millimeter in diameter. It is possible to do this in very thin metal foil with a very fine needle or punch ground to an extremely fine point. With so small a source it is important to exclude dust. The opal glass underneath the hole serves as a protection against dust on one side; the upper surface can be protected with a piece of clear glass.

The comparison source is calibrated by comparing it with a point source of known intensity. To avoid any error due to atmospheric absorption, this source must be placed relatively close to the instrument; the comparison is best done in a laboratory. When the working eye-illumination is of the order 10^{-7} to 10^{-8} foot-candles the intensity of the comparison source must be small; a source situated one hundred feet from the instrument would require an effective intensity of between one-thousandth and one ten-thousandth of a candle. It is not necessary, however, to use a source of such low candle-power, for the same illumination can be obtained with a source of higher intensity (say one-hundredth of a candle-power) used in conjunction with a neutral filter or rotating sector disc of suitable transmission factor. Even the standardisation of a source of this intensity is a matter of considerable difficulty; accurate measurement on an ordinary photometer bench is practically impossible. There is, however, another possible method of calibration, which involves the use of a Maxwellian View type of photometer. The principle of this instrument is discussed later; it will suffice to say here that with this type of instrument an extended photometric field of reasonable brightness can be obtained even with faint point sources. With the aid of such a photometer a source of one-hundredth or one-thousandth of a candle can be compared directly with a small concentrated-filament lamp (a motor-car headlamp is convenient for this purpose). A rotating sector disc or a neutral filter of known low transmission factor, or a combination of both, is interposed in front of the photometer while the lamp is being observed. The lamp can, of course, be calibrated on the bench in the ordinary way. By this method a point source can be calibrated with an error of only a few per cent.

The comparison source is then compared with this source under working conditions. Two methods are available. In the first, the comparison source is set at an arbitrary voltage and the adjustments made by means of the wedge or other means of control, e.g., Nicol prisms. If crossed Nicols are used one should be placed in front of the reflecting plate,

prism, or mirror, and the other between this and the eye. The former should be arranged to rotate, the one nearer the eye being set with its plane of polarisation vertical to avoid any absorption of the partially polarised light reflected from the comparison star. The use of a wedge probably presents less complexity. In the other method, the wedge is removed and the volts on the comparison star are adjusted until equality of candle-power is obtained. This is probably the better method since it permits the working illumination at the eye to be adjusted to any convenient pre-determined level.

The calibration of the wedge or other means of control should preferably be done with the instrument with which it is to be used; particularly if the wedge has diffusing properties. Some results which were obtained during the calibration of a partially diffusing wedge, used in a telephotometer of this type, are instructive. In this instrument the two-point sources were viewed alternately to avoid the effects already mentioned. Curve I in Fig. 2, deter-

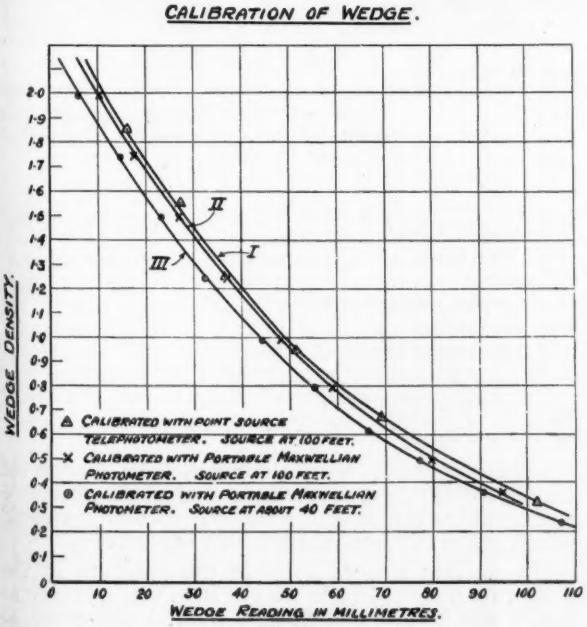
CALIBRATION OF WEDGE.
WEDGE DENSITY.
WEDGE READING IN MILLIMETRES.
II
I
III
△ CALIBRATED WITH POINT SOURCE TELEPHOTOMETER. SOURCE AT 100 FEET.
× CALIBRATED WITH PORTABLE MAXWELLIAN PHOTOMETER. SOURCE AT 100 FEET.
⊙ CALIBRATED WITH PORTABLE MAXWELLIAN PHOTOMETER. SOURCE AT ABOUT 40 FEET.

Fig. 2

mined with this telephotometer, represents a mean curve for two observers. To conform as closely as possible with working conditions the distant light source was situated at about 100 ft. from the instrument. Curve II was obtained independently by means of a portable Maxwellian View photometer, the wedge being placed in front of the instrument. In this case also the distant light source was about 100 ft. from the wedge. The difference between the two curves amounted to about 10 per cent, estimated on their corresponding transmission factors. Curve III was also obtained with the same photometer but with the light source only about 35 ft. from the wedge. The influence of experimental conditions is clearly shown. In the case of a non-diffusing wedge it would probably be much less marked. Even a wedge of this type, however, should be calibrated under working conditions to avoid systematic errors. The wedge can be calibrated by finding points on it which correspond in optical density to sectors of known density.

This type of telephotometer can clearly be used for measurements of atmospheric transmission. A source of known candle-power I is placed at a known distance from the instrument, the distance over which the atmospheric transmission is desired. The wedge is then used to adjust the illumination reaching the eye from this source to equality with that from the comparison star; this latter illumination is obtained by previous or subsequent calibration. Since this illumination, the wedge transmission, and the distance are known, the apparent candle-power of the distant source can be determined by application of the inverse square law, as shown by Paterson and Dudding. The ratio of the apparent to the true candle-power of this source determines the atmospheric transmission. To avoid secular variations, which may be considerable and may thus affect the accuracy of measurements, a substitution method is preferable. In this method the comparison source in the instrument is first calibrated with a source of very low candle-power and then used to determine the candle-power of another more distant source; the instrument is thus calibrated whenever transmission measurements are made.

Accuracy of Measurement.

Very little data seem to have been given in published papers regarding the accuracy of measurements made with stellar photometers of the type under consideration. Middleton ([3]) discusses the probable order of accuracy of the measured atmospheric absorption coefficient α, which he estimates as likely to be correct within 0.05 per kilometre. The atmospheric transmission is given by the quantity $10^{-\alpha}$, so that the corresponding error in the atmospheric transmission measured over a distance of 1 kilometre might amount to about 12 per cent.

Recently the author, in collaboration with some colleagues, attempted to determine under laboratory conditions the accuracy with which two point sources could be compared. One source was an illuminated aperture of known candle-power, subtending at the eye an angle of about 6 seconds of arc. The other source was similar to Middleton's artificial star and consisted of a minute illuminated hole situated at the focus of a lens, and seen by reflection in a prism. The two sources were viewed alternately. The measurements were made at five different levels of illumination in the plane of the eye, varying from 0.8×10^{-8} foot-candles to 2.1×10^{-8} foot-candles. Seven observers took part in the comparison, each observer taking on an average three complete sets of six observations at each illumination level. The comparison was made in each case by adjustment of the voltage on the comparison source. The results suggested that the average error in the mean of six observations was likely to be about 10 per cent. In the measurement of atmospheric transmission two such sets of observations are required, one to calibrate the comparison source, and the other to determine the

apparent candle-power of the distant source relative to that of the comparison source. The corresponding average error in a transmission measurement would appear to be about 14 per cent., which agrees fairly well with the estimate based on Middleton's data. This conclusion is also supported by some laboratory measurements of the transmission factor of various rotating sector-discs; in these measurements the comparison source was operated at a fixed voltage and adjustments were made with a wedge, first without the sector, and then with the sector interposed in front of the distant source. The average error in the measured sector transmissions amounted to about 17 per cent.

In the other type of point-source telephotometer, the so-called extinction type, there is, as already mentioned, no comparison source. One form of instrument described by de Maistre (6), and also used by Pritchard (7) for astronomical measurements, consists of a telescope with a variable-density wedge fitted in the eye-piece. In making an atmospheric transmission measurement two sources of known candle-power are required, one of very low candle-power and small size, situated near the instrument, and the other at the distance over which measurements are to be made. The instrument is directed at each source in turn and the wedge is adjusted until the source is just invisible. From the two wedge readings, the known candle-powers of the two sources and their known distances from the instrument, the atmospheric transmission can be calculated. In this type of telephotometer the readings obtained on any single occasion will depend to some extent on the state of the observer's eye and on its previous history, as well as on the conditions of experiment. Middleton, whose telephotometer can clearly be used as an extinction meter, experimented with this method, but found it far inferior to the artificial star method. Harcombe (8) also found great difficulty in determining the extinction position accurately and consistently.

Before considering other types of telephotometers, it is worth while to inquire for a moment into the possible influence of background brightness on measurements made with point sources. If an ordinary electric lamp is far enough from the observer it has the appearance of a point source. The surrounding background may be illuminated, partly by light received from the source itself and partly by light received from external sources such as the moon or a starlit sky. The threshold illumination at the eye, necessary for a source to be just visible, varies in certain circumstances with the brightness of the background on which it is superimposed. At low values of background brightness the effect is, however, much more marked for parafoveal than for foveal vision; the foveal threshold is, in fact, little affected by background brightness up to about 10^{-5} candles per sq. ft., and changes in background brightness from darkness up to this value should therefore not appreciably affect measurements made with point-source photometers. To minimise the possibility of error owing to changes in background brightness, the brightness of the field surrounding the comparison source may be adjusted to approximate equality with that of the external background; this arrangement was actually adopted by Paterson and Dudding

II.—Diffusing-surface Telephotometers.

One of the simplest forms of apparatus for the measurement of atmospheric transmission consists of an evenly illuminated surface set up at a convenient distance from the observer, and an instrument capable of measuring the brightness of this surface. Ordinary portable illumination photometers are generally unsuited to this purpose, since at very long ranges, such as one mile, the size of the diffusing surface required would be prohibitive; in fact, unless the angular size of the field of the instrument were undesirably restricted, an inconveniently large surface would be required even at considerably shorter ranges. If, however, a telescope is used to look at the surface, the size of the latter can be reduced considerably. Telephotometers used with diffusing surfaces therefore consist of a combination of a telescope and a comparison-of-brightness photometer. Fig. 3 shows the general

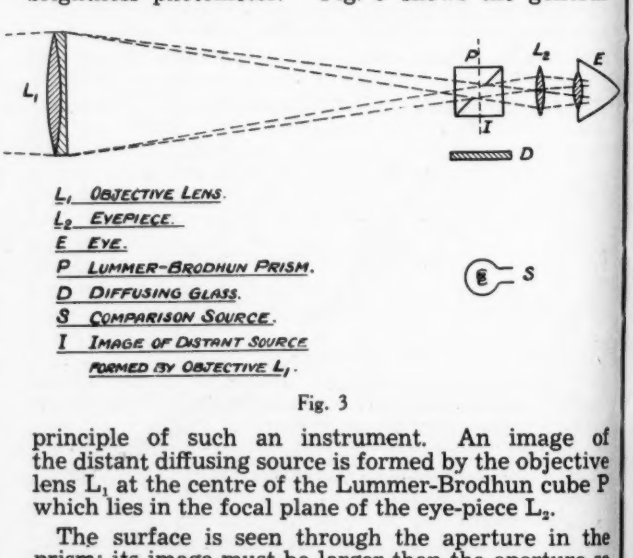

Fig. 3

principle of such an instrument. An image of the distant diffusing source is formed by the objective lens L_1 at the centre of the Lummer-Brodhun cube P which lies in the focal plane of the eye-piece L_2.

The surface is seen through the aperture in the prism; its image must be larger than the aperture so that a continuous photometric field is presented to the observer's eye. The comparison field here consists of a piece of opal glass, or an opaque white diffuser, uniformly illuminated and seen by reflection in the prism. A photometric balance is obtained by varying the illumination of the comparison field; often the comparison lamp is adjustable, and the comparison field illumination is determined by the inverse square law. To avoid the use of an objective of excessive focal length, the prism aperture should not be large. For, with an aperture of $\frac{1}{8}$ in. diameter and an objective lens of 3 ft. focal length, a diffusing surface not less than 5 ft. in diameter would be required for measurements at a range of 3,000 ft. An objective with a focal length of 6 ft. would require a distant source of half this size.

F. A. Benford (9) has described two telephotometers

of this form for use at ranges of 2,300 ft. and 3 miles respectively. The smaller instrument had an objective of 6 in. diameter and 18 ft. focal length; the objective in the larger one had a diameter of 15 in. and a focal length of 30 ft.

In a slightly different form of instrument illustrated in Fig. 4, the prism aperture does not act as a field-of-view stop limiting the area of the distant diffusing surface seen by the observer: it merely

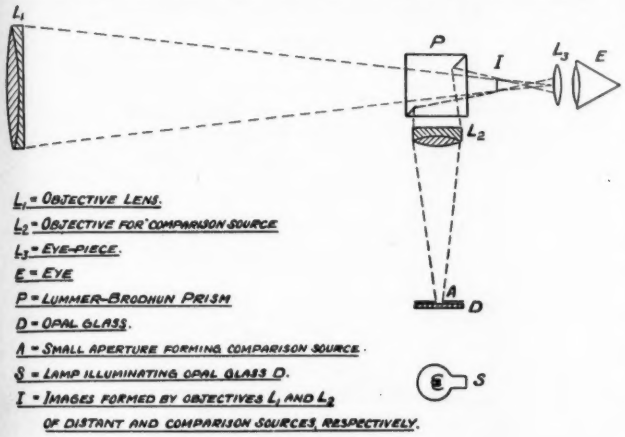

Fig. 4

serves to reflect the light from the comparison field into the eye-piece. A complete image of the distant source is formed at the focus of the eye-piece. Contiguous with it is an image of a comparison surface of similar shape, the two images constituting a continuous symmetrical field, which is seen through the eye-piece. The dimensions of the external and comparison diffusing sources should, for convenience, be chosen to give images of approximately the same size. An instrument designed on these lines has been described by Evans and Chivers([10]). Their instrument is similar to that shown in Fig. 4, except that they have incorporated a reflecting prism between the lens L_2 and the comparison source A to make the instrument more compact. Their distant source consists of a semi-circular aperture in the side of a large internally whitened box illuminated by concealed lamps; the comparison source is a diaphragm of similar shape placed in front of an opaque white diffuser, illuminated by a movable lamp.

The method of calibration is the same for both forms of telephotometer. An illuminated diffusing surface of suitable size and shape is set up about 50 ft. to 100 ft. from the instrument, which is focused on the surface. The illumination on the surface is varied and is measured in turn with the telephotometer and with a portable illumination photometer. The relation between telephotometer readings and screen illumination is thus readily determined. If now an illuminated diffusing surface of similar character and suitable size is set up a great distance away, its apparent illumination can be determined with the calibrated telephotometer; the true illumination of the surface is measured directly by an observer stationed close to it and provided with a portable illumination photometer, preferably the one used in calibration. The ratio of the apparent illumination of the distant source to its true illumination gives the atmospheric transmission between the source and the telephotometer.

The accuracy of the atmospheric transmission measurement will depend on the precision with which the average illumination of the distant screen is measured with the telephotometer and with the portable photometer. Diffusing surfaces of the type under consideration are generally illuminated by a number of concealed lamps arranged round the circumference. With large surfaces it may be difficult to obtain uniformity, and, if the illumination of the surface is not uniform, it is difficult to measure its average value accurately with a portable photometer.

Both during calibration and during atmospheric transmission measurements the instrument is focused on a diffusing surface. In the first case the surface is very much nearer to the instrument than in the second, so that a relatively large movement of the objective is necessary to accommodate the change in focus. If the objective acts as the entrance pupil of the telephotometer the diameter of the beam of light entering the eye is less than that of the eye-pupil, and a correction must be made to allow for this movement.

If absorption losses in the optical components are neglected, a diffusing surface viewed through any optical system appears of the same brightness as when viewed with the naked eye, provided the beam of light entering the eye is as large as, or larger than, the eye-pupil. When the beam of light is smaller than the pupil, the apparent brightness theoretically falls off in the ratio of the area of the beam of light entering the eye to the area of the eye-pupil ([11]); theoretically, because there is another factor which influences the apparent brightness and which is due to an effect discovered by Stiles and Crawford. This effect is discussed in connection with Maxwellian View telephotometers. When the objective acts as the entrance pupil, the area of the beam is not constant, but depends on the position of the objective relative to the eye-piece. This will be clear from Fig. 5. A B represents the position of the objective during calibration at short range; the full lines H H′ and K K′ show the diameter of the beam entering the eye. A′ B′ represents the position of the objective when the instrument is focused for long range

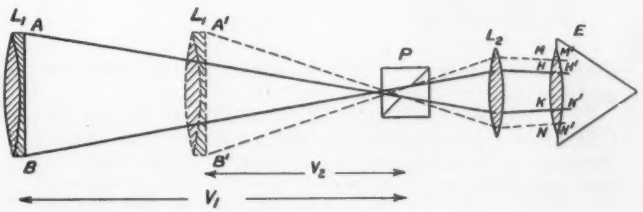

Fig. 5. Diagram showing change in exit pupil area with position of objective when objective acts as stop.

work; the dotted lines M M′, N N′ indicate the diameter of the beam in this case. The apparent brightnesses in the two cases will be proportional to the areas of the corresponding beams at H K and M N. The area of the beam from the comparison source is always the same. Hence, if the apparent brightness of a constant diffusing surface is measured first when close to the telephotometer and then at long range, the apparent brightness measured at long range will appear greater than that determined when the source is close. To make the results comparable, a correction must be applied to allow for the change in exit-pupil area. It can be shown that, in the absence of Stiles-Crawford effect, this correction is equal to the ratio of the square of the distance of the objective from the image of the source when the latter is at long range to the square of the distance of the objective from the image during calibration, that is to V_2^2 divided by V_1^2. This ratio can be readily determined from the known distance of the source in the two cases and the focal length of the objective. All illumination values determined at long range must be corrected to make them comparable with the values obtained during calibration. The necessity for a correction can be avoided if the beam emerging from the eye-piece has a constant area whatever the position of the objective. This can be achieved by the insertion of a stop of suitable diameter at some convenient position in the telephotometer, for example, at the eye-piece, as shown in Fig. 6. If the area of the emergent beam were

Fig. 6

determined uniquely by the eye-pupil, no artificial pupil would be required.

The telephotometers of Benford and of Evans and Chivers were developed for the purpose of measuring atmospheric transmission. Their advantages are that the transmission is obtained directly as the ratio of two measurements, that the distances of the sources do not enter into the determination, and therefore need not be known very accurately, and that the telephotometer can be used by any observer capable of using a comparison-of-brightness photometer. Their disadvantages are their bulk and weight, which are determined by the diameter and focal length of the objective lens and by the disposition and method of control of the comparison source.

Telephotometers of this type, but much smaller than those mentioned above, have been designed for special purposes. Waldram ([12]) has described a small compact instrument for model work and for measuring the brightness of road surfaces (Fig. 7).

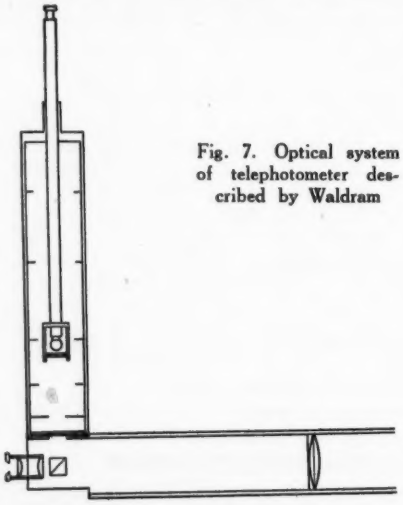

Fig. 7. Optical system of telephotometer described by Waldram

The telephotometer consists of a small telescope with a very small prism photometer at its focus. One principal plane of the prism has a very small patch of silvering on it about ¾ mm. by ½ mm., divided symmetrically by a very narrow horizontal slit through which the model or road surface is seen; the silvered patch is illuminated by an arrangement similar to that used in the Macbeth Illuminometer.

III. Maxwellian View Telephotometers.

The usefulness of the Maxwellian View principle lies in the fact that a photometric field of convenient angular dimensions and of convenient brightness can be obtained in circumstances which make the use of ordinary photometers impossible.

If a lens or mirror is used to form at the pupil of the eye a real image of a source of light, the whole surface of the lens or mirror appears uniformly bright. The arrangement is shown in Fig. 8 (a). S is the light source, L the lens, and E the eye-pupil. There are two ways in which the principle may be used. When the source is an extended diffusing surface, the image of which is larger than the eye-pupil, the apparent brightness of the lens is, if absorption losses in the lens are neglected, equal to that of the surface seen with the naked eye. If, on the other hand, the image formed by the lens is smaller than the eye-pupil, so that all the light collected by the lens enters the eye, the brightness of the lens is directly proportional to the total candle-power of the source and the square of the focal length of the lens and inversely proportional to the square of the dis-

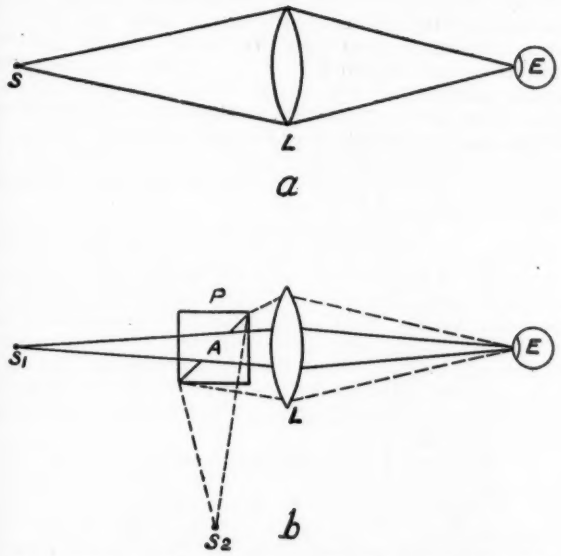

Fig. 8. Diagrams illustrating Maxwellian View principle and its photometric application.

tance of the source from the focus of the lens. It is this second arrangement which is of practical importance in telephotometry.

It may be of interest to compare the flux E per unit solid angle, incident on the eye with this arrangement, with the corresponding flux E′ per unit solid angle which the eye would receive from a diffusing surface by which the lens was replaced. If it is assumed that the normal pupillary diameter is 5 mm., the ratio of E to E′ for a lens of 15 cm. focal length is 3,600; with a focal length of 50 cms. the flux per unit solid angle received from the lens would be 40,000 times as great as that received from the diffusing surface. From this it will be clear that the arrangement has great advantages in the measurement of the candlepower of sources which are of low intensity, or which are a long way off.

When two such lens surfaces are arranged to be in juxtaposition, we have the necessary conditions for a photometer. One way of achieving this is by the insertion of a prism P in front of the lens, as show in Fig 8 (b), so that the light from a second source S_2 is reflected into the eye through the lens. This method was adopted in a photometer described by Fabry and Buisson ([13]). An alternative method is shown in Fig. 9a. Here two lenses L_1 and L_2 are used together with a Lummer-Brodhun prism P, one lens being seen directly through the prism and the other by reflection. This system was adopted by Gehlhoff and Schering ([14]), whose instrument is shown in Fig. 9 (b). An image of a given source S_1 is formed in the plane of the eye-ring E by the objective lens L_1. The lens L_2 forms, in the same plane, an image of the comparison source S_2. The illumination falling on L_2 from the comparison source is controlled by Nicol prisms placed at N. When the observer places his eye at the eye-ring two concentric photo-

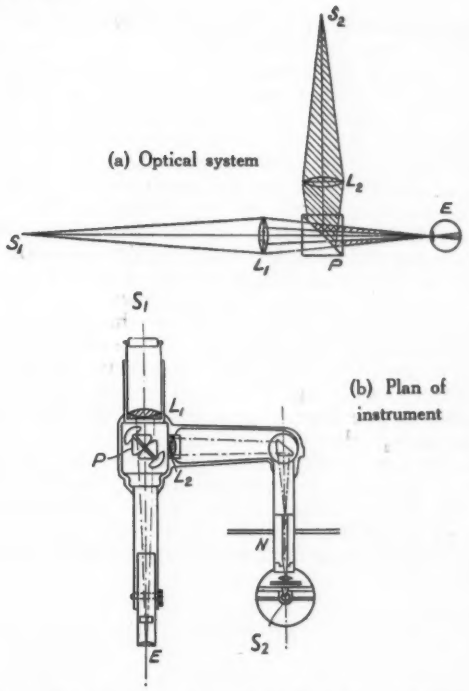

Fig. 9. Telephotometer designed by Gehlhoff and Schering.

metric fields are seen. The lens L_1 can be focussed by rack and pinion. In an instrument designed by Crawford ([15]) only one half of the photometric field is arranged for Maxwellian View; the other half is formed by direct reflection of the diffusing surface H in the prism C. (Fig. 10.) The lens F of focal length F C allows the eye to focus comfortably without accommodation on the photometric field at C. The

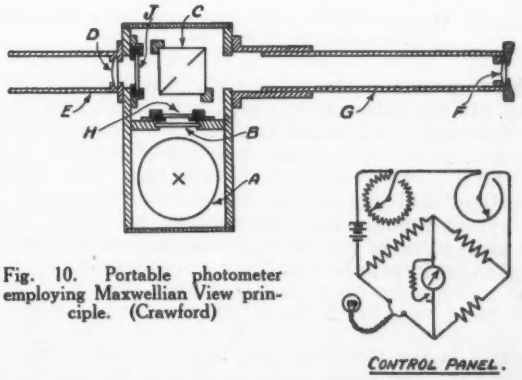

Fig. 10. Portable photometer employing Maxwellian View principle. (Crawford)

brightness of the comparison field is adjusted by varying the current in the comparison lamp. Large changes in the lamp current, which would alter the colour as well as the brightness, are avoided by the use of calibrated neutral filters. The comparison

lamp and leads form one arm of a Wheatstone bridge, the other arms of which are constant. The instrument, which is both compact and handy, can be used for measuring either surface illumination or candle-power. In addition to the two methods of varying the illumination of the comparison field already mentioned, variable-density wedges of good quality or variable diaphragms can be used; or the position of the comparison lamp may be altered.

Since the brightness of the lens surface is proportional to the illumination reaching the lens and to the square of the focal length of the lens an adequate field brightness can be ensured, even when the illumination from the source is very low, by increasing the focal length. In instruments not designed to be moved there might be no objection to the use of lenses of relatively long focus (from 1 metre upwards); in instruments designed to be transportable there would be a practical limit to the focal length.

The field-brightness can, however, be increased without sacrificing transportability, by a method adopted in a Maxwellian View telephotometer designed at the National Physical Laboratory ([16]) for measurements of atmospheric transmission over distances up to ten thousand feet. In this instrument (Fig. 11) the main objective L_3 is fixed, and an image of the source is focused in the eye-ring by an independent focusing system consisting of the two lenses L_1 and L_2. L_1 is adjustable by rack and pinion; L_2 is fixed and acts as a collimator; thus the image can always be focused into the eye-ring R, which lies in the focal plane of L_3. With this arrangement the field brightness is proportional to the expression:—

$$I \frac{f_1^2}{f_2^2} \frac{f_3^2}{x^2}$$

where I is the candle-power of the source, x its distance from the focus of L_1 and f_1, f_2, and f_3 are the respective focal lengths of the focusing lens, the collimator, and the main objective. In the N.P.L. instrument the objective L_3 has a focal length of 50 cm. Normally the focusing lens L_1 and the collimator L_2 are each of 10 cm. focal length. For measuring very low illuminations, however, the 10 cm. focusing lens can be replaced by one of 25 cm. focal length, thus increasing the field-brightness six and one-quarter times without increasing the power of the object-source. This arrangement is often advantageous under field conditions, where power-supply limitations frequently prohibit the use of high-intensity lamps. In the absence of the focusing system the same increase in field-brightness could only be achieved by using an objective of 125 cm. focal length, and thereby sacrificing ease of transport.

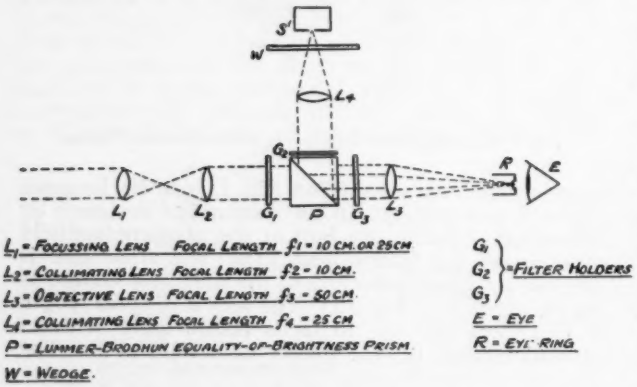

Fig. 11. Optical system of Telephotometer employing Maxwellian View principle, (Collier and Taylor).

An image of the comparison source S', a very small illuminated diffusing window, is also formed in the eye-ring. A variable-density wedge W, with a linear characteristic, controls the brightness of the comparison field. G_1, G_2, and G_3 are slides for the introduction of filters. If it is desired to work with light of a particular colour a filter of that colour can be inserted at G_3 in both beams of light. To focus the instrument on a source the eye-ring is replaced by an eye-piece fitted with cross wires.

The eye-ring is large enough to allow all the light from both sources to enter the eye; its main function is to exclude stray light by ensuring that of the total light collected by the instrument from objects in front, only that derived from a region subtending a small angle at the telephotometer reaches the observer's eye. With a 2 mm. eye-ring the angle is about ten minutes of arc. The mechanical details of the instrument are shown in Fig 12.

With the 10 cm. focusing lens fitted to the instrument a lamp of 150 candles one mile away gives an adequate field-brightness (about one-twentieth of a candle per square foot) when atmospheric absorption is not large. When the atmospheric absorption is high, or when measurements are required over greater distances, the 10 cm. focusing lens may be replaced by the 25 cm. lens. On fairly clear nights the use of this lens would, without the use of lamps of higher candle-power, extend the working range to between eight and ten thousand feet.

To determine the atmospheric transmission over any given distance two lamps of known candle-power are required. One of these is placed at the required distance and the other as close to the telephotometer as possible. The measurement consists in determining the apparent candle-power of the distant lamp in terms of that of the nearer one; the ratio of the apparent and true candle-power of the distant lamp gives the atmospheric transmission directly. The distances of the two lamps from the telephotometer must be measured accurately.

The adoption of this substitution method eliminates any uncertainty due to possible variations in the candle-power of the comparison lamp from day to day, and also reduces effects of secular variations in the observer's criterion of a brightness match. Neutral filters are inserted when required to avoid large changes in field brightness, only the final adjustment being made with the wedge. It is not necessary to know the absolute values of wedge density: a knowledge of the rate of change of density with wedge-scale reading is all that is required. This can be determined with considerable accuracy by comparing different parts of the wedge with rotating sector discs of known optical density.

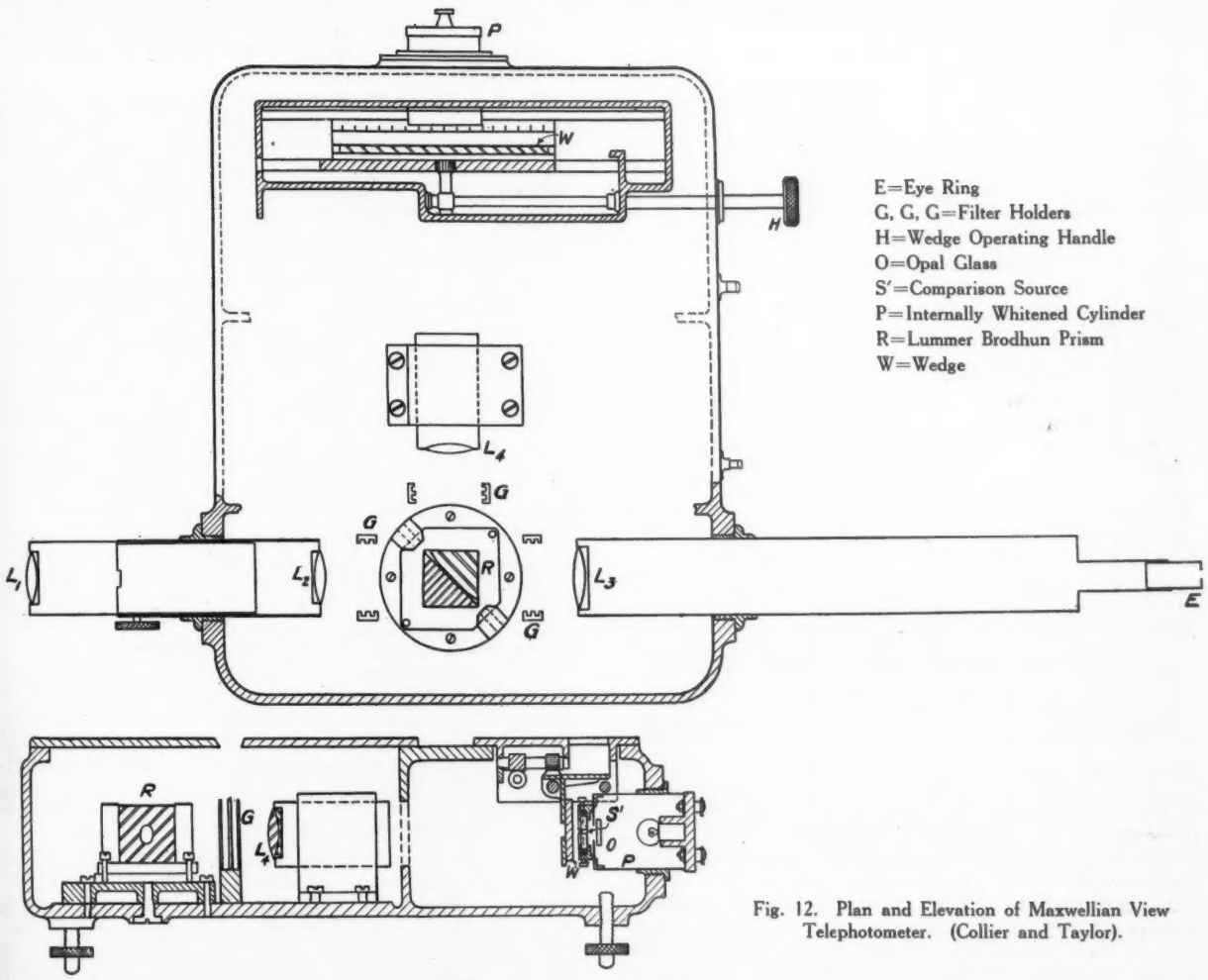

Fig. 12. Plan and Elevation of Maxwellian View Telephotometer. (Collier and Taylor).

The candle-powers of the lamps placed close to the telephotometer should clearly be kept as low as possible; on the other hand, they must be high enough to be measurable on a photometer bench.

Concentrated-filament lamps, underrun to have an intensity of about one candle, are convenient. Alternatively underrun low-wattage opal lamps may be used. It is true that these must be placed further away on account of their greater size; but, on the other hand, their directional candle-powers are less affected by small errors in alignment.

Theoretically, the minimum distance at which the nearer lamp can be placed is determined by the eye-ring. This must be larger than the image of the source in order to admit all the light collected from the source. On this basis the limit would be reached when the diameter of the eye-ring was just equal to that of the observer's eye-pupil.

There is, however, an upper limit to the size of the image; this limit is determined by a factor of which the simple theory takes no account.

Stiles and Crawford([17]) have shown that the luminous sensation produced by a narrow beam of light entering the eye and terminating on the retina is not independent of the region in the eye-pupil through which the beam passes. In their measurements a Maxwellian beam of fixed small cross-sectional area in the plane of the eye-pupil was traversed across the pupil in steps; a second Maxwellian beam of approximately the same cross-sectional area was directed through the centre of the eye-pupil. At each step they compared the brightness of the fields due to the two beams. They found that the apparent brightness of the field due to the movable beam was a maximum when the beam entered at a point near to, but not necessarily at, the centre of the eye-pupil. Their results are illustrated by the curve in Fig. 13. Here the ordinates represent the luminous efficiency of the beam at any given point in the traverse, that is, the ratio of the apparent field brightness at that point to the maximum apparent field brightness.

Since the relative efficiency is known for each

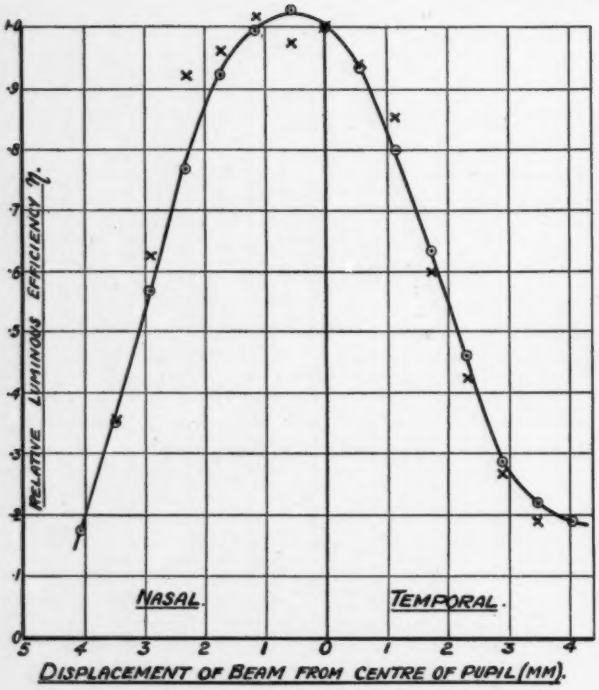

Fig. 13. Horizontal Traverse. Subject B.H.C. Right Eye.
⊙ Mean Results of Flicker Method.
× Single Set of Measurements by Equality of Brightness Method.

elementary area at which the beam enters the eye-pupil, the relative efficiencies of pupils of any size and shape can, as Stiles and Crawford pointed out, be determined by graphical integration. Clearly, the relative efficiency decreases with increase of pupil area.

In Maxwellian View telephotometers used for candle-power measurements the effective pupil-area is determined by the area of the image formed in the eye-ring by the optical system. This area depends on the size of the source and its distance from the instrument; it is certainly not constant. The influence of change in pupil-area on measurements must therefore be considered.

If a number of sources of different area but of known relative candle-power are placed in turn at any convenient distance from the telephotometer, the apparent candle-power of each source can be determined with respect to that of the smallest. The ratio of the measured value of relative candle-power to the true value will be a measure of the pupil efficiency. If also the corresponding image sizes are measured with a microscope they can be related to the measured pupil efficiencies. Some results which were obtained in this way with the N.P.L. telephotometer are shown in Fig. 14. Within the limits of experimental error there was no difference between the measured and true values of relative candle-power for image diameters up to about half a millimetre; hence for image diameters not exceeding half a millimetre the pupil efficiency may with sufficient accuracy be regarded as constant.

To ensure constancy of pupil efficiency during measurements with ordinary lamps the lamps must be placed at such distances that their image diameters in the eye-ring are not greater than half a millimetre. If the telephotometer is fitted with the 10 cm. focusing lens, a 6-watt motor-car headlamp can safely be used at a distance of 30 ft.; the corresponding distance for a 15-watt opal lamp is about 180 ft. If, however, the image diameter exceeds half a millimetre, a correction can be applied to allow for the change in pupil efficiency. For a 1 mm. image the correction is about three per cent.; for a 2 mm. image it is about eleven per cent.

Fig. 15 also shows clearly the effect of change in pupil efficiency. In this case the apparent candle-power of a given source was measured with the source at various distances from the telephotometer, so that the size of the image in the eye-ring changed progressively; the maximum distance was 100 ft. The ordinates represent the apparent candle-power of the source at any distance, relative to its apparent candle-power at 100 ft. The five curves are for sources of different sizes. The crosses in the top curve represent corrected values of relative candle-power when change in pupil efficiency is allowed for.

This phenomenon will occur in any Maxwellian photometer used for candle-power measurements, or in any other form of photometer in which the exit pupil is not constant. The quantitative effects of the phenomenon will depend on the eye of the individual observer, the size of the source, its distance, the magnification of the instrument, and possibly on the rate of divergence of the beam.

It is appropriate to mention here a characteristic which is peculiar to Maxwellian View telephotometers. When the light-source is situated a long way off, the image formed in the eye-ring is exceedingly small, so that light transmitted to the eye by the objective lens passes through only a very small area of the eye-pupil. The appearance of the photometric field is consequently affected by imperfections in the eye. These imperfections include lack of homogeneity of the eye media, which produces some patchiness, and specks and other mobile bodies

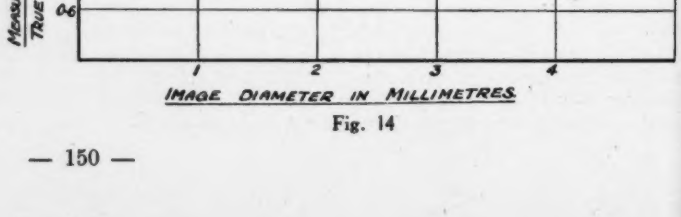

Fig. 14

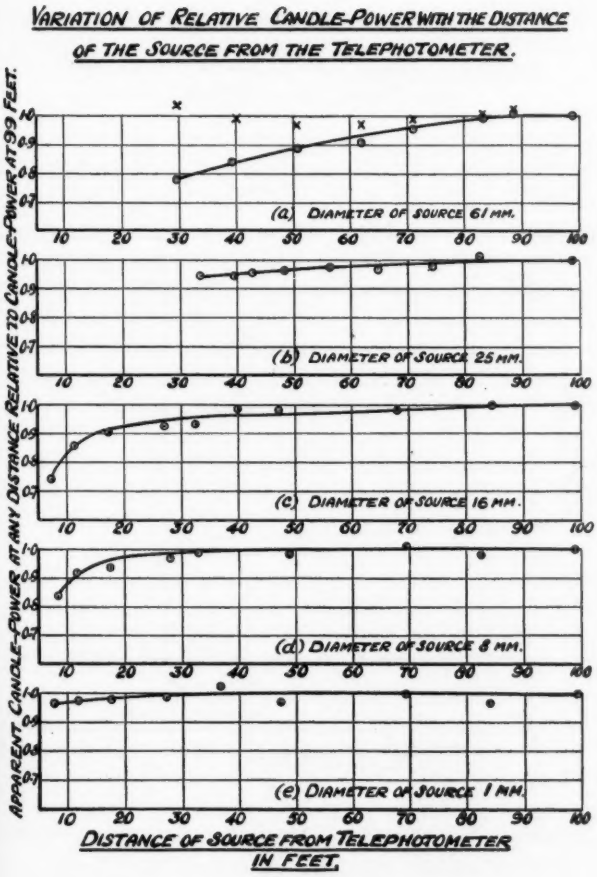
VARIATION OF RELATIVE CANDLE-POWER WITH THE DISTANCE OF THE SOURCE FROM THE TELEPHOTOMETER.
APPARENT CANDLE-POWER AT ANY DISTANCE RELATIVE TO CANDLE-POWER AT 99 FEET.
(a) DIAMETER OF SOURCE 61 MM.
(b) DIAMETER OF SOURCE 25 MM.
(c) DIAMETER OF SOURCE 16 MM.
(d) DIAMETER OF SOURCE 8 MM.
(e) DIAMETER OF SOURCE 1 MM.
DISTANCE OF SOURCE FROM TELEPHOTOMETER IN FEET.

Fig. 15

(known as Muscae Volitantes) which produce moving shadows. It might be thought that the imperfect field appearance would seriously affect the accuracy of observations. While it is true that the appearance is rather disconcerting to an observer, when he encounters it for the first time, it has been found that in the case of an experienced observer the field appearance does not appreciably affect the precision of measurement. Fig. 16 furnishes examples of the agreement between observers. The full and broken curves show simultaneous values of transmission over a range of 3,170 ft., obtained by two observers using separate Maxwellian telephotometers of similar design. The maximum difference which occurred when the transmission was rising rapidly amounted to about 16 per cent.; the average difference was 6 per cent.

The dotted curves in the same figure show corresponding values obtained with a non-Maxwellian telephotometer using diffusing sources. Except when the transmission was changing rapidly the two methods rarely differed by more than about 6 per cent.; even when conditions were unsteady the difference seldom exceeded 15 per cent.

The curves in Fig. 17 refer to transmission values obtained by four observers working in pairs with the same two Maxwellian telephotometers; the plotted points are mean values for each pair of observers.

The N.P.L. telephotometer has also been compared, with satisfactory results, with a projector method of measuring atmospheric transmission. In this method the apparent candle-power of the projector was measured with ordinary photometric equipment at two stations 4,220 ft. apart, the nearer station being 2,700 ft. from the projector. Some of the results are shown in Fig. 18.

The use of Maxwellian View telephotometers is not confined to measurements of atmospheric transmission. The N.P.L. instrument has been used for determining the transmission factors of dense fogs over distances up to 120 ft. A high-candle-power projector lamp is required and the experimental technique must be modified to allow for the effect of diffuse light. Fog transmission factors as low as one-fifth of one per cent. have been measured both in daylight and at night, although with an accuracy much less than that obtainable when diffuse light is absent. Other possible uses of Maxwellian telephotometers include the measurement of the candle-power of traffic and other signals under the conditions in

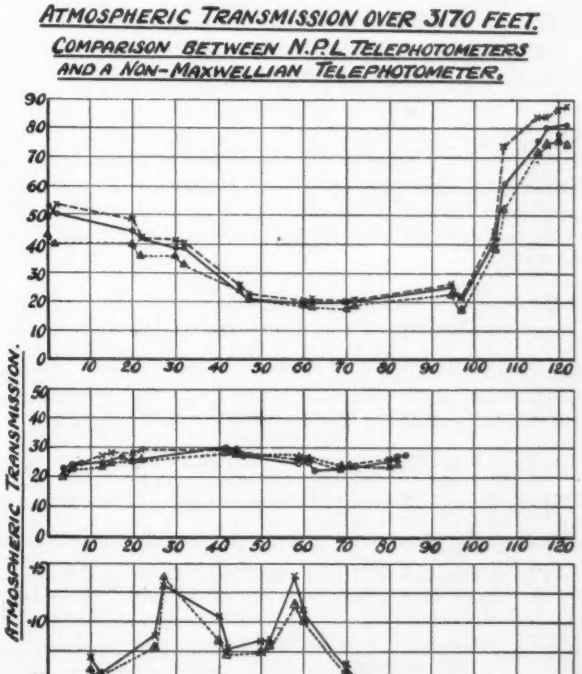
ATMOSPHERIC TRANSMISSION OVER 3170 FEET.
COMPARISON BETWEEN N.P.L. TELEPHOTOMETERS AND A NON-MAXWELLIAN TELEPHOTOMETER.
ATMOSPHERIC TRANSMISSION.
MEASUREMENTS MADE WITH FIRST N.P.L. TELEPHOTOMETER
" " " SECOND " "
" " " NON-MAXWELLIAN TELEPHOTOMETER.
TIME IN MINUTES.

Fig. 16

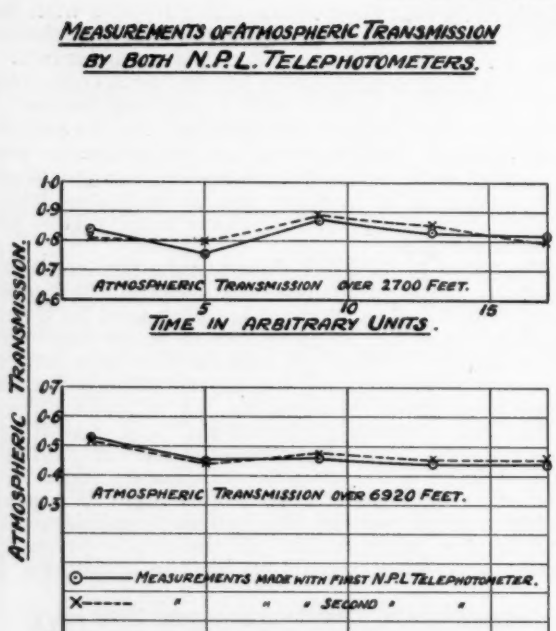
MEASUREMENTS OF ATMOSPHERIC TRANSMISSION BY BOTH N.P.L. TELEPHOTOMETERS.
ATMOSPHERIC TRANSMISSION.
ATMOSPHERIC TRANSMISSION OVER 2700 FEET.
TIME IN ARBITRARY UNITS.
ATMOSPHERIC TRANSMISSION OVER 6920 FEET.
MEASUREMENTS MADE WITH FIRST N.P.L. TELEPHOTOMETER.
" " " SECOND " "
TIME IN ARBITRARY UNITS.

Fig. 17

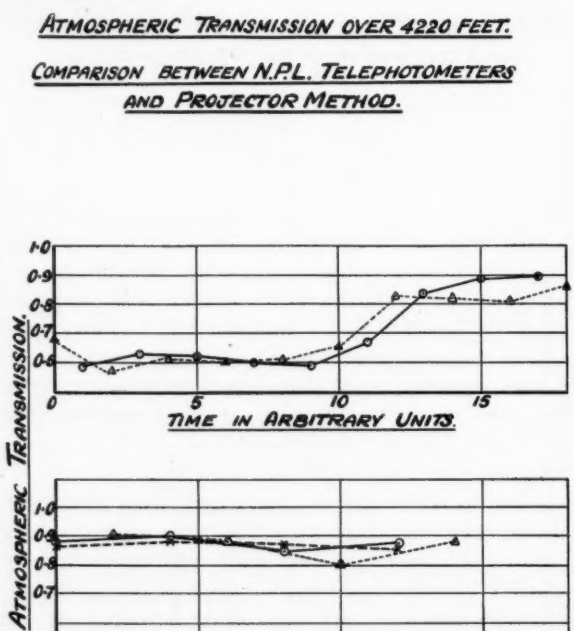
ATMOSPHERIC TRANSMISSION OVER 4220 FEET.
COMPARISON BETWEEN N.P.L. TELEPHOTOMETERS AND PROJECTOR METHOD.
ATMOSPHERIC TRANSMISSION.
TIME IN ARBITRARY UNITS.
MEASUREMENTS MADE WITH FIRST N.P.L. TELEPHOTOMETER.
" " SECOND " "
" " PROJECTOR METHOD.
TIME IN ARBITRARY UNITS.

Fig. 18

which they are usually seen, the measurement of the intensities of faint sources of light, including stars, and the comparison of the brightnesses of extended surfaces; they could also be employed for road brightness measurements if a small enough eye-ring were fitted.

The author wishes to record his thanks to Mr. W. G. A. Taylor, of the Photometry Division of the N.P.L., for his continued interest and assistance in the preparation of this paper, and to Mr. B. H. Crawford, M.Sc., A.Inst.P., also of the Photometry Division, for his very helpful criticism of the first section.

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(17) W. S. Stiles and B. H. Crawford. Proc. Roy. Soc. B., 112, 1933, p. 428.

See also, in connection with (1) (2) (6) and (7) above: J. W. T. Walsh. Photometry, Ch. XV. (Stellar Photometry), p. 424.

DISCUSSION

COLONEL C. H. SILVESTER EVANS, in opening the discussion, congratulated the lecturer on a most masterly summary of the different methods employed. He could fully appreciate the difficulties which the author had encountered, having been in competition with him on several occasions. He had found, he said, that there was difficulty in inducing the ordinary observer to employ satisfactorily the Maxwellian View type of instrument, the use of which required a great deal of practice. In certain circumstances, especially in hazy weather, he would hesitate to ask an unskilled observer to use an instrument of this type.

Colonel Evans agreed that precision instruments of the type described are very cumbersome, and that the particular instrument mentioned, in the designing

of which Mr. Collier had taken a major part, was by no means a "portable" instrument. It was transportable, but if one had to carry one hundredweight one might just as well carry three or four hundredweight.

For many years they had made atmospheric transmission measurements as continuously as possible during their experiments, but there was a limit to the speed at which an observer could work. Now, he hoped, they were within reach of an automatic recording instrument of sufficient accuracy, which would save many a night's work, at present rejected.

There was another difficulty. None of the instruments so far described could be used for other than horizontal measurements, but in many problems it was necessary to go up to 8,000 ft. (and later perhaps 20,000 ft.) at all angles up to the vertical. A recording instrument might enable that to be done.

Dr. F. J. W. WHIPPLE said that the meteorologist was very much concerned in these atmospheric transmission measurements, but he called it estimating visibility or visual range. Much depended upon what was taken as the criterion of visibility and in this meteorologists had many problems of their own. In practice, they had essentially to estimate the contrast between some selected object and its background. It had been estimated that the minimum contrast perceptible might amount to 2 per cent., but that was a very high standard and the figure was probably nearer 4 per cent. At night they had to judge from prevailing conditions what the visual range would be by day and enter that in their records. With an experienced observer these estimates were not as coarse as might be supposed, but they would welcome any instrument that would enable them to make objective measurements of transmission up to distances of three or four miles or more, say, by observing a 50-watt lamp. At present they often had to extrapolate from observations made at short range for the transmission up to twenty or thirty miles, a proceeding about which he was very sceptical.

Dr. Whipple then described in connection with the field effects of the Maxwellian View the images that appear when a pin-head is observed at very close range and asked if any present could give an explanation.

Mr. S. HARCOMBE added his appreciation of the paper and said that he was very familiar with the work of Mr. Collier and his colleagues. He did not agree with Colonel Evans about portability, but he thought that they had now reached the limit of accuracy that could be expected from any instrument of that size. With the telephotometer described, an observer could be trained to an accuracy of about 5 per cent., which was adequate for transmission measurements. He was pleased to observe the good agreement secured in results obtained by the various instruments.

At Portsmouth they used the projector method. He still thought that it was the best method of all, but the apparatus was certainly not portable. If one had an instrument larger than the N.P.L. model one could not improve on accuracy but might then carry out Dr. Whipple's measurements on a 50-watt lamp at three or four miles.

Following Mr. G. H. Wilson's suggestion, Mr. Collier agreed to reply to each speaker at the conclusion of his remarks.

Replying to those who had already spoken, Mr. L. J. COLLIER said the difficulties that arose from the use of the Maxwellian View were probably less in foggy weather owing to the greater diffusion and the consequent reduction of the unsteady effects associated with the inequalities in the eye of the observer. Increasing the range of a Maxwellian View telephotometer meant either increasing the size of the lamps to 300 or 400 watts (and using bigger batteries) or increasing the focal length of the lens and consequently the bulk of the instrument. However, it would be possible to make a lighter instrument with the same range. The present instrument, with larger lamps, was capable of satisfying Dr. Whipple's requirements at three or four miles; a range of twenty miles was at present out of the question. He expressed the hope that he might have an opportunity of examining Colonel Evans's recording telephotometer.

Dr. F. J. W. WHIPPLE then asked whether the N.P.L. telephotometer could be used to estimate the magnitude of the brighter stars. Mr. Collier replied that he had no experience of this class of work, but he could not accept the 1 per cent. accuracy claimed by some investigators for the comparison of stellar intensities. He thought 5 to 10 per cent. was more likely.

Mr. J. M. WALDRAM emphasised the care that was necessary to ensure any accuracy at all, and briefly described the points of his own instrument designed to measure atmospheric transmission over the shorter ranges associated with street lighting and aerodrome floodlighting. The instrument was an illuminometer which could be adapted to work as a telephotometer with a distant diffusing screen. Its special features were a small photometric field, 0.75 mm. by 1 mm. (specially made under the microscope), and the use of the telephoto lens to give long focal length combinations within a reasonable compass. The instrument had quite a good magnification which enabled it to be used to get directly transmission measurements up to 1,000 ft. while still remaining portable. An earlier model had been much lighter, but they had finally built the present one which was heavy and comparatively stable.

Mr. L. J. COLLIER said that he was very interested in the telephotometer, particularly the use of the telephoto lens principle, and wondered whether it would have application to instruments employing Maxwellian View.

Mr. H. J. A. TURNER explained how the telephotometer Mr. Waldram had just described was used in measurements on aerodrome floodlights. He showed

the diffusing screen so constructed as to appear uniformly bright from any viewpoint. Measurements of its brightness were made at every 100 ft. up to 1,000 ft. and from the results the atmospheric transmission could be found to an accuracy of about 10 per cent., which was generally sufficient for their purpose. The small field of the instrument was not, however, very easy to use, but after practice one could get consistent results.

Mr. J. FRENCH asked Mr. Collier whether movement in the Maxwellian View telephotometer was of great importance or whether it was lost in the greater "field effects" fluctuations.

Mr. L. J. COLLIER replied that although that type of instrument was certainly uncomfortable at first an observer can become adapted to it. He would have a big spread of observations when using it for the first time—between 30 per cent. and 40 per cent., for example—but after a fortnight's practice he would have a spread of only 5 per cent. to 10 per cent. A number of observers without previous experience had made measurements at various times, and after a little training they were able to get consistent results.

Mr. J. M. WALDRAM mentioned the difficulty of measuring with non-uniform fields as, for example, road surfaces seen in the telephotometer.

Mr. G. H. WILSON asked what were the angular dimensions of the fields of the N.P.L. telephotometer, and went on to say that in experiments they had found considerable spread in their results when using the projector method and plotting illumination against the inverse square of the distance. The telephotometer had given much more consistent results.

Mr. L. J. COLLIER said, referring to slides shown previously, that there had been very good agreement between his own results and those of Mr. Harcombe who used the projector method.

Colonel C. H. SILVESTER EVANS said he would hesitate to use the projector method over the comparatively short distances which Mr. Wilson was using, and Mr. Harcombe would agree that at short range the form of the beam became very important.

Mr. J. S. PRESTON stressed the influence of stray light on the telephotometer in fog, and said he thought that the inaccuracies introduced would be greater with a point source than with an extended source. Referring to the visibility measurements of Dr. Whipple, one could use a telephotometer in daylight to measure directly the contrast in brightness. Alternatively, one might measure the brightness of the fog itself against a blackened cube as background and compare that measurement with the brightness of a white test disc somewhere near the instrument. The relation between these figures would give the veiling power of the fog and might have a definite relation to what is ordinarily known as visibility.

Mr. L. J. COLLIER agreed that there was a big correction for fog. The light was diffused and the amount entering the eye was determined by the diameter of the eye-ring. A rough correction could be made by measuring the brightness of the fog just beside the lamp.

Mr. J. M. WALDRAM mentioned his own experience in street lighting where the brightness of a test plate was increased by some 10 per cent. over a distance of 40 ft.

In closing the meeting, Mr. G. T. WINCH, who presided, made brief reference to several points. He said that where selective transmission introduced colours in the photometer field it would be advisable to keep the field small. There was a difficulty of getting sufficient light to work photoelectric devices in telephotometers, but some recent work on the brightness of television images had produced sufficiently stable amplifiers to bring telephotometers almost within the scope of photoelectric photometry. But the apparatus again would not be portable and he sympathised with those who sought to make their instruments both accurate and portable.

The meeting concluded with a hearty vote of thanks to Mr. Collier for his paper, to Dr. Long of the Westminster Technical Institute for the use of the room.

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A GAUGE FOR SITING OF LIGHT SOURCES ON BENDS

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(Communicated.)

The exact siting of street lighting sources is now recognised as being most important. The appearance of a street lighted by any street lighting system is built up from individual bright areas on the roadway, one formed by each light source; and since these bright areas are always formed in line with the observer and the light source, the importance of carefully siting the sources is obvious. For an even brightness of the road surface the sources should be so placed that, as a driver proceeds along the road, no large gaps appear between them, and consequently no dark gap is left between the corresponding bright areas.

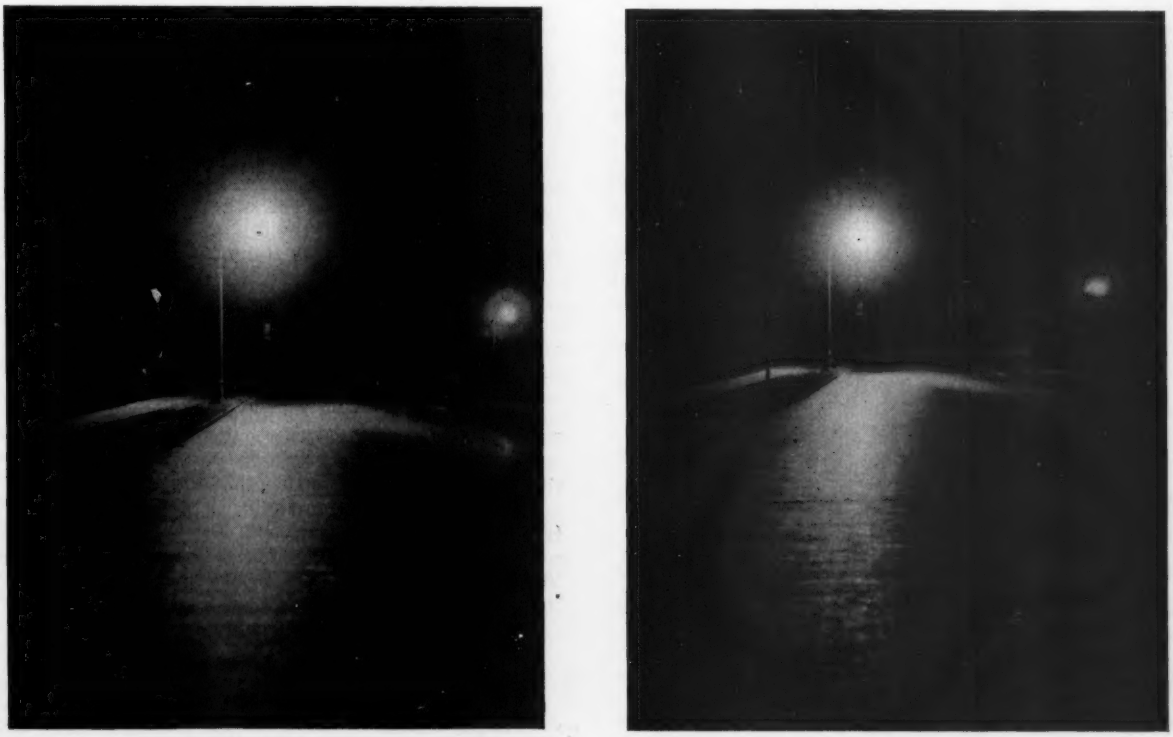
On a straight road of normal width this is not difficult; but when the road is not straight, even when the curvature or the change of direction appears on plan to be insignificant, the sources tend to be widely separated in perspective, and siting becomes critical.

The separation between objects in perspective represents the angle which they subtend at the observer, and methods have been devised by the author for measuring the limiting angular separation between two light sources at known distances, if an unpleasing dark area between them is to be avoided.*

Two typical bright areas from lanterns having a non-cut-off distribution, but at different distances, are shown in Fig. 1. If the light sources producing them are well sited so that the bright areas tend to merge into one another, the resulting brightness distribution is shown in Fig. 2, which shows the sources at the greatest tolerable separation.

If two light sources having a known light distribution are placed over a given road surface at known distances and mounting height, and located at the limiting separation, then the distance (in perspective) from the centre line of the bright area formed by one source to the centre line of the dark area formed between the two bright areas, can be taken as the effective half-width of the bright area. (See Fig. 2.) The effective width so measured does not vary greatly according to the distance away of the mating source, and its relation to the distance of this source is shown

*J. M. Waldram. Ill. Eng. (London), 1934, p. 307; G. H. Wilson, E. L. Damant, J. M. Waldram. I.E.E. Jour.; Vol. 79, No. 477, September, 1936, p. 241; G. H. Wilson, A.P.L.E., 1938, p. 7.



Viewpoint 200-ft. distant. *Viewpoint 300-ft. distant.*

Fig. 1. Two typical bright areas from lanterns having a non-cut-off distribution but at different distances.

by the full curve of Fig. 3, for one given set of conditions.

The light distribution and road surface to which this set of data applies are typical, and it appears

Fig. 2. Illustration showing merging of bright areas when the light sources are well sited.

that reasonable variations of distribution and road surface do not produce very great variations in the patch width. The results are in good agreement with the figures given in the M.O.T. final report, paragraph 46. These data can be immediately used in installation design; for evidently, if dark areas are to be avoided, the sources must be so placed that two apparently adjacent sources should never appear to be separated by an angle greater than the sum of the two half patch widths. For example, in Fig. 4, sources 5 and 7 when seen from A are separated by eight degrees, whereas the half widths given by the full curve of Fig. 3 for the distances concerned are $2.2^\circ + 0.6^\circ = 2.8^\circ$. These sources are thus badly sited.

The practical use of the data as it stands in designing a lay-out is not particularly easy: it is necessary

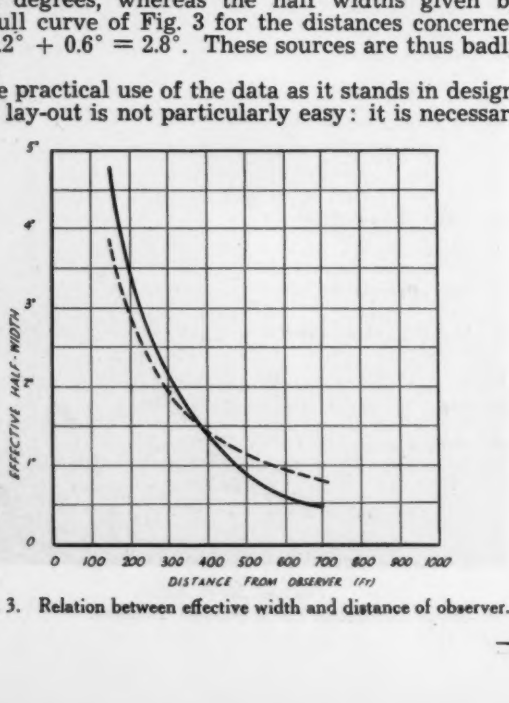


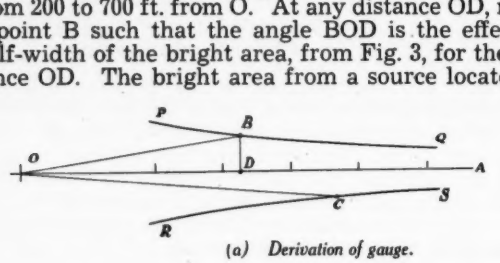
Fig. 3. Relation between effective width and distance of observer.

Fig. 4. An example of imperfect siting (sources 5, 6 and 7).

to make a trial lay-out, and to check the angles concerned at a number of positions, and this must be repeated whenever a source position is varied, working from both directions of traffic.

The checking of a layout can be greatly simplified by the use of the gauge to be described, which is derived from the curve of Fig. 3. Its construction is as follows:

In Fig. 5 (a), let O represent an observer and OA a line of sight. Mark along OA a scale of distances from 200 to 700 ft. from O. At any distance OD, mark a point B such that the angle BOD is the effective half-width of the bright area, from Fig. 3, for the distance OD. The bright area from a source located at



(a) *Derivation of gauge.*

(b) *Gauge drawn to scale.*

Fig. 5. Gauge for checking lay-out of sources.

B on plan will appear just to cover up to the line OA, provided that one other source, such as C, is present on the other side of OD so as to cover up to that line from the other side. The line PBQ is the locus of points such as B, and RCS its mirror image for the other side of the line. Any two sources, lying one on PBQ and the other on RCS, will leave a just tolerable dark region between them as seen from O. Fig. 5 (b) shows the gauge to scale.

Such a gauge can be readily used in checking a lay-out. If it is drawn on tracing paper to the scale of the street plan, and if O is placed on the plan at any position at which a driver may be, then it should be impossible to lay the gauge OPQSR between any two sources, which will appear when seen from O to be adjacent (for example, in Fig. 4, sources 5 and 7 appear to be adjacent when seen from A). If the gauge passes easily between them they are too widely separated, and a dark area will be formed between them. The point O is moved from one position to another up the street, and all sources in view checked very quickly. For example, in Fig. 6 the gauge passes easily between 5 and 7 from position A; evidently 6 is on the wrong side of

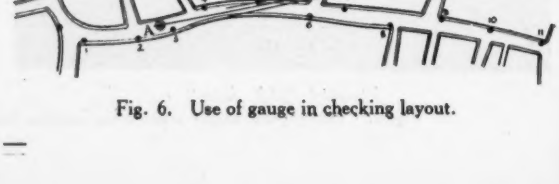


Fig. 6. Use of gauge in checking layout.

the road. In checking a trial lay-out the siting must, of course, be checked for both directions of traffic and all reasonable viewpoints.

For convenience a circle of 10 ft. radius is drawn to scale, with O as centre. The usual position of a driver is taken as 10 ft. from the kerb, and O will be correctly placed in most cases if the circle touches the kerb.

The gauge of Fig. 5 is slightly tapered, being 24 ft. wide at 200 ft. and 17 ft. wide at 700 ft., with practically straight sides. It was suggested to the author that probably no great change in lay-out would result if a parallel gauge were used. This assumes that the patch width is inversely proportional to the distance of the source, which is not strictly true. The curve shown broken in Fig. 3 is the patch width/distance curve assumed in using a gauge 20 ft. wide. In practice, however, very little change in siting results from the use of this gauge in place of the tapered gauge, and it is even simpler to draw.

It is found in practice that there is no need to check sources which are further away than 700 ft., or nearer than 200 ft. In many cases it is impossible to obtain perfect siting for traffic in both directions, owing to the presence of junctions, entrances, etc., which call for a compromise in the positions of sources. Similarly, on very sharp bends the use of the gauge may result in impracticably short spacings, and common sense calls for a waiving of the rule of angular separation of sources, relying for visibility upon, for example, illuminated buildings or other backgrounds at the bend.

In any case, siting of sources calls for a great deal of skill and experience, and the indications of the gauge must be regarded as only a good guide rather than as an infallible rule. No amount of paper planning can render unnecessary a careful inspection of the road itself; for local circumstances, such as trees, telephone wires, garage entrances, slight inclines or vertical curves, road surfaces, possibility of a misleading arrangement of sources, and many other matters may need consideration in settling the final siting. Many of these things do not appear on plans, but they may either make it impossible to place a source at its intended position or may render the bright area from it ineffective.

NOTICES

Admission Cards for Meetings.—Members and Visitors are reminded that, in accordance with the new arrangements approved by the Council for the present Session, admission cards should in all cases be presented in order to gain access to meetings.

Only those who have inadvertently omitted to bring cards need sign the attendance register.

In this way it is hoped to expedite entry to lecture halls, besides preserving a more complete record of attendance.

This applies to all meetings held in London (both General and Sectional).

Registration for Sectional Meetings.—Members of the Society of all classes are entitled to attend meetings of the various Specia Sections.

In order to ensure the receipt of notices of forthcoming meetings, however, all Members desirous of attending meetings (and likewise any friends of Members who wish to join as Visitors) should send in their names and address to the secretaries of the respective Sections, whose names and addresses appear in the List of Members.

The I.E.S. Library.—Preliminary work on the collection of a nucleus of books on Illumination and Photometry and allied subjects has now been practically completed by Mr. J. B. Score Smyth who, as honorary librarian, undertook the classification of volumes and prepared a card-index. The library is housed at 32, Victoria Street, London, and is now open for the inspection by Members.

A printed list of available books and particulars of rules in regard to their use will be published shortly. In the meantime the opportunity is taken of gratefully acknowledging the valuable services of Mr. Score Smyth and the numerous donations of Members in the form of books and contributions to the Library Fund.

Courses in Illuminating Engineering.—The attention of Members is drawn to the courses of lectures on Illumination, intended to cover the syllabus of the City and Guilds Examination, which have been organised at the Borough Polytechnic (Borough Road, London, S.E 1), the Northampton Polytechnic (St. John Street, London, E.C.1), and the South-East London Technical Institute (Lewisham High Road, London, S.E.4).

Courses of lectures on Illumination have also been arranged to take place at the University of Sheffield during the Autumn and at the College of Technology, Leeds, during the Spring,

The organisation of such courses, following the initiation of Examinations in Illuminating Engineering under the auspices of the City and Guilds Institute is a development of great interest to the Society. It is hoped, therefore, that leading firms in the lighting industry, and especially those who are Sustaining Members of the Society, will encourage the younger members of their staffs to attend.

SYNOPSIS OF MEETINGS

LONDON.

Oct. 17th. Lighting Faults (W. Robinson); *Junior Institution of Engineers, 39, Victoria Street, S.W.1.*

Oct. 21st. Siting Street Lamps; *E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, W.C.2.*

Oct. 25th. Trend of Decorative Lighting (A. B. Read); *Besant Hall, Gloucester Place, W.1.*

Oct. 27th. Lighting Practice in U.S.A. (H. A. Lingard); *E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, W.C.2.*

Nov. 8th. Visibility of Street Lighting (C. Dunbar, F. C. Smith and J. M. Waldram); *Institution of Mech. Engrs., Storey's Gate, Westminster, S.W.1.*

Nov. 14th. Elec. Discharge Lamps in Industry (C. A. Hughes); *Home Office Industrial Museum, Horseferry Road, S.W.1.*

Nov. 16th. Combined Tungsten and Elec. Discharge Lighting (W. R. Stevens); *E.L.M.A. Lighting Service Bureau, 2, Savoy Hill, W.C.2.*

MANCHESTER.

Nov. 16th. Visibility of Street Lighting; *Engineers' Club, Albert Square* (7.15 p.m.).

LEEDS.

Nov. 18th. Annual Dinner Dance, *Powolnys, Bond Street.*

BIRMINGHAM.

Oct. 21st. Opening Meeting (Exhibits), *White Horse Hotel, Congreve Street.*

Nov. 25th. Glass Manufacture (W. M. Hampton); *White Horse Hotel, Congreve Street.*

GLASGOW.

Oct. 19th. Lighting of the Empire Exhibition (R. O. Ackerley); *"The Gordons," 19, Gordon Street.*

Nov. 15th. Exhibition of Lighting Equipment; *Room 149, Royal Technical College.*

DUBLIN.

Oct. 18th. Physics of Light (W. H. Poole); *Engineers' Hall, 35, Dawson Street.*

Nov. 15th. Photometry (H. B. Ruff); *Engineers' Hall, 35, Dawson Street.*

N.B. *Unless otherwise announced all meetings commence at 7 p.m.*

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